

A_{LT} in the Nucleon-Nucleon Polarized Drell-Yan Process

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We present a leading order (LO) estimate for the longitudinal-transverse spin asymmetry (A_{LT}) in the nucleon-nucleon polarized Drell-Yan process at RHIC and HERA- \vec{N} energies in comparison with A_{LL} and A_{TT} . A_{LT} receives contribution from g_1 , the transversity distribution h_1 , and the twist-3 distributions g_T and h_L . For the twist-3 contribution we use the bag model prediction evolved to a high energy scale by the large- N_c evolution equation. We found that A_{LT} (normalized by the asymmetry in the parton level) is much smaller than the corresponding A_{TT} . Twist-3 contribution given by the bag model turned out to be negligible.

The nucleon-nucleon scattering provides us with a new opportunity to probe nucleon's internal structure. In particular, polarized Drell-Yan lepton pair production opens a window toward new types of spin dependent parton distributions – chiral-odd distributions $h_1(x, \mu^2)$ and $h_L(x, \mu^2)$ which can not be measured by the deep inelastic lepton-nucleon scatterings [1]. There are three kinds of double spin asymmetries in the nucleon-nucleon polarized Drell-Yan process: They are A_{LL} (collision between the longitudinally polarized nucleons), A_{TT} (collision between the transversely polarized nucleons), and A_{LT} (longitudinal versus transverse). The experimental data on these asymmetries will presumably be reported by RHIC at BNL and HERA- \vec{N} at DESY. By now several reports are already available for the estimate of A_{LL} and A_{TT} in the next-to-leading order (NLO) level [3]. In this talk we present a first estimate on A_{LT} in comparison with A_{LL} and A_{TT} at RHIC and HERA energies in the LO QCD [4]. A_{LT} is particularly interesting, since it receives the twist-3 contribution as a leading contribution (although it is proportional to $1/Q$), giving a possibility of seeing quark-gluon correlation in hard processes.

In LO QCD, the double spin asymmetries are given by

$$A_{LL} = \frac{\sigma(+,+) - \sigma(+,-)}{\sigma(+,+) + \sigma(+,-)} = \frac{\Sigma_a e_a^2 g_1^a(x_1, Q^2) g_1^{\bar{a}}(x_2, Q^2)}{\Sigma_a e_a^2 f_1^a(x_1, Q^2) f_1^{\bar{a}}(x_2, Q^2)}, \quad (1)$$

$$A_{TT} = \frac{\sigma(\uparrow, \uparrow) - \sigma(\uparrow, \downarrow)}{\sigma(\uparrow, \uparrow) + \sigma(\uparrow, \downarrow)} = a_{TT} \frac{\Sigma_a e_a^2 h_1^a(x_1, Q^2) h_1^{\bar{a}}(x_2, Q^2)}{\Sigma_a e_a^2 f_1^a(x_1, Q^2) f_1^{\bar{a}}(x_2, Q^2)}, \quad (2)$$

$$A_{LT} = \frac{\sigma(+, \uparrow) - \sigma(+, \downarrow)}{\sigma(+, \uparrow) + \sigma(+, \downarrow)} = a_{LT} \frac{\Sigma_a e_a^2 [g_1^a(x_1, Q^2) x_2 g_T^{\bar{a}}(x_2, Q^2) + x_1 h_L^a(x_1, Q^2) h_1^{\bar{a}}(x_2, Q^2)]}{\Sigma_a e_a^2 f_1^a(x_1, Q^2) f_1^{\bar{a}}(x_2, Q^2)}, \quad (3)$$

where $\sigma(S_1, S_2)$ represents the Drell-Yan cross section with the two nucleon's spin S_1 and S_2 , e_a represent the electric charge of the quark-flavor a and the summation is over all quark and anti-quark flavors: $a = u, d, s, \bar{u}, \bar{d}, \bar{s}$, ignoring heavy quark contents (c, b, \dots) in the nucleon. The variables x_1 and x_2 refer to the momentum fractions of the partons coming from the two nucleons "1" and "2", respectively. In (2) and (3), a_{TT} and a_{LT} represent the asymmetries in the parton level defined as $a_{TT} = \sin^2\theta \cos 2\phi / (1 + \cos^2\theta)$ and $a_{LT} = (M/Q)(2 \sin 2\theta \cos \phi) / (1 + \cos^2\theta)$, where θ and ϕ are, respectively, the polar and azimuthal angles of the virtual photon in the center of mass system with respect to the beam direction and the transverse spin. We note that A_{LL} and A_{TT} receive contribution only from the twist-2 distributions, while A_{LT} is proportional to the twist-3 distributions and hence a_{LT} is suppressed by a factor $1/Q$.

The twist-3 distributions g_T and h_L can be decomposed into the twist-2 contribution and the "purely twist-3" contribution:

$$g_T(x, \mu^2) = \int_x^1 dy \frac{g_1(y, \mu^2)}{y} + \tilde{g}_T(x, \mu^2); \quad h_L(x, \mu^2) = 2x \int_x^1 dy \frac{h_1(y, \mu^2)}{y^2} + \tilde{h}_L(x, \mu^2). \quad (4)$$

The purely twist-3 pieces \tilde{g}_T and \tilde{h}_L can be written as quark-gluon-quark correlators on the lightcone. In the following we call the first terms in (4) $g_T^{WW}(x, \mu^2)$ and $h_L^{WW}(x, \mu^2)$ (Wandzura-Wilczek parts).

For the present estimate of A_{LT} , we use the LO parametrization for f_1 by Gluück-Reya-Vogt [5] and the LO parametrization (standard scenario) for g_1 by Gluück-Reya-Stratmann-Vogelsang (GRSV) [6]. For h_1 , g_T and h_L no experimental data is available up to now and we have to rely on some theoretical postulates. Here we assume $h_1(x, \mu^2) = g_1(x, \mu^2)$ at a low energy scale ($\mu^2 = 0.23 \text{ GeV}^2$) as has been suggested by a low energy nucleon model [2]. These assumptions also fix g_T^{WW} and h_L^{WW} . For the purely twist-3 parts \tilde{g}_T and \tilde{h}_L we employ the bag model results at a low energy scale, assuming the bag scale is $\mu_{bag}^2 = 0.081$ and 0.25 GeV^2 . In particular, we set the strangeness contributions to the purely twist-3 contributions equal to zero. By these boundary conditions for h_1 , g_T and h_L at a low energy side and applying the relevant μ^2 evolution to them, we can estimate A_{LT} .

The μ^2 evolution of the twist-3 distributions is quite complicated [7]. However, it has been proved that at large N_c their μ^2 -dependence can be described by a simple DGLAP evolution equation similarly to the twist-2 distributions and the correction due to the finite value of N_c is of $O(1/N_c^2) \sim 10 \%$ level [8]. Here we apply this large- N_c evolution to the bag model results [9].

The double spin asymmetries are the functions of the square of the center-of-mass energy $s = (P_1 + P_2)^2$ (P_1 and P_2 are the four momenta of the two nucleons), the squared invariant mass of the lepton pair $Q^2 = (x_1 P_1 + x_2 P_2)^2 = x_1 x_2 s$ ($M^2 \ll Q^2$) and the Feynman's $x_F = 2q_3/\sqrt{s} = x_1 - x_2$. Using these variables, momentum fractions of each quark and anti-quark in (1)-(3) can be written as $x_1 = (x_F + \sqrt{x_F^2 + (4Q^2/s)})/2$ and $x_2 = (-x_F + \sqrt{x_F^2 + (4Q^2/s)})/2$.

Figure 1 shows the three asymmetries normalized by the asymmetries in the parton level, $\tilde{A}_{LL} = -A_{LL}$, $\tilde{A}_{TT} = -A_{TT}/a_{TT}$, $\tilde{A}_{LT} = -A_{LT}/a_{LT}$. They are plotted as a function of x_F for fixed values of $Q = \sqrt{Q^2}$ ($= 8, 10 \text{ GeV}$) and \sqrt{s} ($= 50, 200 \text{ GeV}$), which are

within or close to the planned RHIC and HERA- \vec{N} kinematics. ($50 \text{ GeV} < \sqrt{s} < 500 \text{ GeV}$ for RHIC, and $\sqrt{s} = 39.2 \text{ GeV}$ for HERA- \vec{N} .) \tilde{A}_{LL} and \tilde{A}_{TT} are symmetric with respect to $x_F = 0$, while \tilde{A}_{LT} is not symmetric as is obvious from the kinematics. In general all these asymmetries are larger for larger Q^2/s . \tilde{A}_{LT} with only the twist-2 contributions in g_T and h_L are shown by solid lines. They are typically 5 to 10 times smaller than \tilde{A}_{LL} and \tilde{A}_{TT} . \tilde{A}_{LT} with complete g_T and h_L is shown by the short dash-dot ($\mu_{bag}^2 = 0.25 \text{ GeV}^2$) and the dotted ($\mu_{bag}^2 = 0.081 \text{ GeV}^2$) lines. Since large $|x_F|$ corresponds to small x_1 or x_2 , and the bag model prediction for the distribution function becomes unreliable in the small- x region, we only plotted these lines for the region $x_1, x_2 > 0.07$. As can be seen from Fig. 1, the purely twist-3 contribution brings only tiny correction to \tilde{A}_{LT} . Larger value of the bag scale μ_{bag}^2 would not make it appreciably larger. The smallness of \tilde{A}_{LT} can be ascribed to the factors x_1 or x_2 in (3). In the kinematic range considered either x_1 or x_2 (or both) take very small values. If it were not for those factors, \tilde{A}_{LT} would be comparable to \tilde{A}_{LL} and \tilde{A}_{TT} . We remind in passing that what is measured experimentally is A_{LT} itself which receives the suppression factor M/Q from a_{LT} .

To summarize, we presented a first estimate of the longitudinal-transverse spin asymmetry A_{LT} for the polarized Drell-Yan process at RHIC and HERA- \vec{N} energies in comparison with A_{LL} and A_{TT} . A_{LT} normalized by the asymmetry in the parton level turned out to be approximately five to ten times smaller than the corresponding A_{TT} , although the prediction on its absolute magnitude suffers from the uncertainty of the distributions, in particular, of h_1 as was the case for A_{TT} . The purely twist-3 contribution to g_T and h_L was modeled by the bag model, and it turned out its effect on A_{LT} is negligible compared with the Wandzura-Wilczek contribution to g_T and h_L .

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Figure 1. Double spin asymmetries, \tilde{A}_{LL} , \tilde{A}_{TT} , \tilde{A}_{LT} , for the polarized Drell-Yan using the GRSV parton distribution and the bag model at $Q = 8, 10 \text{ GeV}$ and $\sqrt{s} = 50, 200 \text{ GeV}$. The solid line denotes \tilde{A}_{LT} with only the Wandzura-Wilczek contributions in g_T and h_L . The short dash-dot line denotes \tilde{A}_{LT} with the bag scale $\mu_{bag}^2 = 0.25 \text{ GeV}^2$, and the dotted line denotes \tilde{A}_{LT} with the bag scale $\mu_{bag}^2 = 0.081 \text{ GeV}^2$. The long dashed line corresponds to \tilde{A}_{LL} , and the long dash-dot line corresponds to \tilde{A}_{TT} .